In re Patent Application of:
LANG ET AL
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IN THE DESCRIPTION

Please replace **the title** of the invention with the following amended title:

"**EXTENDED CAVITY LASER DEVICE WITH BULK TRANSMISSION GRATING**"

Please replace the identified paragraphs of the published specification with the following amended paragraphs:

[0022] In accordance with another aspect of the invention, a laser apparatus for producing a frequency-doubled laser radiation is provided, comprising a Littrow-stabilized laser apparatus having at least the laser diode, a collimating means, and a transmission grating, for producing an output laser beam at the fundamental frequency.

[0023] ~~a. a Littrow-stabilized laser apparatus having at least the laser diode, a collimating means, and a transmission grating, for producing an output laser beam at the fundamental frequency.~~ In a preferred embodiment the laser apparatus includes a nonlinear element such as periodically poled LiNbO.sub.3 crystal or waveguide, optically aligned with the Littrow-stabilized laser apparatus to receive the output laser beam at the fundamental frequency, for producing a frequency-doubled output beam in the short-wavelength range of the visible optical spectrum or in the UV range by means of second harmonic generation in the nonlinear element.

[0038] A semiconductor laser diode chip 100 mounted on a carrier 103 has a high-reflection coated back facet 105 and an

anti-reflection coated front facet 110. The laser diode is capable of emitting a high power coherent light beam 115 in a single spatial mode having a wavelength in the red or near-infrared region of the optical spectrum. The laser diode is optically coupled through a collimating means 120 to a bulk diffraction grating 135. The collimating means 120 at least partially collimates the light beam 115 to form a beam 126 hereinafter referred to as the at least partially collimated laser diode beam 126, or simply as the laser diode beam 126. The bulk diffraction grating 135 is oriented to diffract a portion of the laser diode beam 126 back into the laser diode to provide optical feedback, as schematically shown by an arrow 117. The collimating means 120 is shown to be a single lens but alternatively can be a collimating lens or more typically a system of collimating lenses. According to the invention the grating 135 is a transmission grating. A portion of the laser diode beam 126 ~~130, which is at least partially collimated by the collimating means 120,~~ passes through the transmission grating 135 forming an output laser beam 140.

[0042] With reference to FIGS. 4a and 4b, the transmission grating 135 can be either a surface relief grating having a periodically corrugated surface ~~410~~ 411 etched or drawn in a transparent material ~~400~~ 401 such as glass, or a holographic grating optically written in a photo-sensitive material 440 supported by a substrate 430. In both cases, to suppress specular reflections from the back surface of the gratings, an anti-reflection coating ~~410~~ 137 can be applied to the back surface. An antireflection coating can also be applied to the front surface of a holographic grating.

[0045] In another embodiment, said alignment can be achieved by rotating the laser diode carrier 103 about an optical axis 101 of the laser diode as shown schematically in FIG. 2a by a curved double-sided arrow 99.

[0050] With reference to FIGS. 3a and 3b, a preferred astigmatism-correcting and collimating lens system for use with a high-power type laser chip 100 includes a cylindrical lens 300 together with a collimation lens 320. The light beam 115~~123~~ from the laser diode 100 is partially collimated by the cylindrical lens 300 in the transverse direction perpendicular to the plane of the active region 97 of the laser diode 100 so that it has substantially the same beam divergence in the transverse direction as it has in the lateral direction parallel to the plane of the active region 97. By placing the cylindrical lens 300 at the position where the transverse size dimension of the light beam 115~~123~~ has expanded to equal the lateral size dimension of the beam 115 ~~123~~ and by picking the focal length of the cylindrical lens 300 to achieve the aforementioned partial collimation, the ~~output~~ laser diode beam 126 outputted from the lens 320 is made symmetric and free of astigmatism.

[0051] Another aspect of the present invention provides a frequency-converted laser apparatus comprising the Littrow-stabilized laser diode of the first aspect of the present invention optically coupled to an out-of-cavity nonlinear element to produce frequency-converted coherent radiation from the laser output beam 140. According to this aspect of the invention, the laser output beam 140 is preferably a high-

power beam as described hereinafter, and will also be referred to herein as the high-power beam 140 in the context of the frequency conversion.

[0053] With reference to FIG. 6, the Littrow-stabilized laser diode 1 comprising the laser diode chip 100, the collimating means 120, and the transmission grating 135, produces the at least partially collimated high-power beam 140 having substantially circular symmetry in a plane perpendicular to the direction of propagation. A nonlinear element 155 is positioned to receive the high power ~~light~~ beam 140 from the Littrow-stabilized laser diode 1. The nonlinear element 155 is capable of generating a second light beam 157 having a wavelength in the ultraviolet, blue or green range of the spectrum from a portion of the optical power of the ~~first~~ high-power beam 140. The second beam 157 has a wavelength which is different from that of the ~~injected~~ high-power beam 140. A dichroic filter 165 may be placed at the output of nonlinear element 155 to block the ~~first~~ high-power beam, e.g. by reflecting it as an infrared dump beam 175 away from the optical path, and to pass the frequency-converted second beam as the output 170 of the laser apparatus. Additional collimating or collimating and focusing means 150 and 160 can be disposed between the Littrow-stabilized laser diode 1 and the nonlinear element 155, and between the nonlinear element 155 and the dichroic filter 165, respectively, for collimating or collimating and focusing the high power ~~laser~~ beam 140 and the second beam 157. ~~145~~.

[0054] An optical isolation means 145 can be disposed between the Littrow-stabilized laser diode 1 and the nonlinear element

155 to pass the high-power ~~laser output~~ beam 140 and to block a back-reflected portion of the ~~laser~~ high-power beam 140 from returning back into the laser diode chip 100 through the transmission grating 135. The back reflected portion of the ~~laser~~ high-power beam 140 can be for example due to reflections from the collimating means 150 and from the nonlinear element 155. The optical isolation means 145 can be a commercially available optical isolator.

[0058] The configuration shown in FIG. 6 is a single pass second harmonic generation or frequency-doubling configuration in which the nonlinear element is a bulk crystal of nonlinear optical material. The spot size of the beam 155 in the crystal is optimized for maximum single pass conversion efficiency by focusing the beam to the smallest possible spot size such that the beam still remains focused over the length of the crystal. In the case of a potassium niobate bulk crystal with a length of 1 cm and a 1 Watt infrared input power of the high-power beam 140 from the Littrow-stabilized laser diode 1~~00~~, the output power of the blue frequency doubled beam 170 is about 10-20 mW. Using longer crystals the second harmonic generated output can be increased since the conversion efficiency increases linearly with the crystal length. In this single pass configuration the high power ~~laser diode~~ beam 140 is focused in the nonlinear crystal 155.

[0063] In FIG. 9 a double-pass frequency-doubling configuration is shown in accordance with the present invention. The ~~laser~~ high-power beam 140 emitted by the Littrow-stabilized laser diode 1 in accordance with the present invention is collimated and focused by a lens system 152 into a nonlinear crystal 155. The nonlinear crystal 155

has a reflective coating 255 integrated on a surface which is opposite from the input side that receives the high-power beam 140. The coating 255 reflects at least a substantial portion of the beam 140 as well as the frequency doubled light generated by the nonlinear crystal material 155. A beamsplitter 153 which is transmissive for light having the fundamental frequency but reflective of the frequency doubled light 170 is positioned in the return path of the light beam between the lens system 152 and the nonlinear crystal 155 in order to couple the frequency doubled blue light 170 out of the laser system. The retro reflector 255 should be slightly misaligned from the laser beam so that the light reflected back toward the laser is misaligned from the laser output facet. Care should be taken that the phase of the reflection from the mirror 255 is the same for the fundamental and the second harmonic generated beam to prevent phase mismatch and reduced output efficiency.